CHAPTER - VI

NON DESTRUCTIVE TESTING AND EVALUATION

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6.1 INTRODUCTION

Nondestructive testing (NDT), also called nondestructive evaluation (NDE) and nondestructive inspection (NDI), is testing that does not destroy the test object. The activity primarily involves looking at (or through) or measuring something about an object to determine some property of the object or to determine whether the object contains irregularities, discontinuities, or flaws. The terms irregularity, discontinuity, and flaw can be used interchangeably to mean something that is questionable in the part or assembly, but specification, codes, and local usage can result in different definitions for these terms. As all these terms describe what is being sought through testing, inspection, or examination, the term NDE (nondestructive evaluation) has come to include all NDE used to find, locate, and sizing flaws and allow the investigator to decide whether or not the object or flaws are acceptable. A flaw that has been evaluated as rejectable is usually termed a defect.

NDE is vital for constructing and maintaining all types of components and structures. To detect different defects such as cracking and corrosion, there are different methods of testing available, such as X-ray (where cracks show up on the film) and ultrasound (where cracks show up as an echo blip on the screen). This article is aimed mainly at industrial NDT, but many of the methods described here can be used to test the human body. In fact methods from the medical field have often been adapted for industrial use, as was the case with phased array ultrasonics and computed radiography.

While destructive testing usually provides a more reliable assessment of the state of the test object, destruction of the test object usually makes this type of test more costly to the test object's owner than nondestructive testing. Destructive testing is also inappropriate in many circumstances, such as forensic investigation. That there is a tradeoff between the cost of the test and its reliability favors a strategy in which most test objects are inspected nondestructively.

Nondestructive evaluatio n can be conveniently divided into nine distinct areas:

- Flew detection and evaluation
- Leak detection and evaluation
- Metrology (measurement of dimension) and evaluation
- Location determination and evaluation
- Structure or microstructure characterization
- Estimation of mechanical and physical properties
- Stress (strain) and dynamic response determination
- Signature analysis
- Chemical composition determination

The popular NDT techniques used for the above are:

- Visual Testing,
- Liquid Penetrant Testing,
- Magnetic Particle Testing ,
- Eddy Current Testing,
- Radiography Testing,
- Ultrasonic Testing,
- Acoustic Emission Testing,
- Infrared Thermography.

In the present paper, the discussion would mainly pertain to the above mentioned techniques.

6.2 NON-DESTRUCTIVE TEST TECHNIQES

Visual Testing

Visual Testing is very important, though neglected by many NDT personnel. Visual Inspection is a nondestructive testing technique that provides a means of detecting and examining a variety of surface flaws, such as corrosion, contamination, surface finish, and surface discontinuities on joints(for example, welds, seals, solder connections, and adhesive bonds). Visual inspection is also the most widely used method for detecting and examining surface cracks, which are particularly important because of their relationship to structural failure mechanism. Even when other nondestructive techniques are used to detect surface cracks, visual inspection often provides a useful supplement. For example, when the eddy current examination of process tubing is performed, visual inspection is often performed to verify and more closely examine the surface disturbance. Given the wide variety of surface flaws that may be detectable by visual examination, the use of visual inspection may encompass different techniques, depending on the product and type of surface flaw being monitored. The methods of visual inspection involve a wide variety of equipment, ranging from examination with the naked eye to the use of interference microscopes for measuring the depth of scratches in the finish of finely polished or lapped surfaces. Some of the equipments used to aid visual inspection includes:a) flexible or rigid borescopes for illuminating and observing internal, closed or otherwise inaccessible areas, b) image sensors for remote sensing or for the development of permanent visual records in the form of photographs, videotapes, or computer-enhancedimages, c) magnifying systems for evaluating surface finish, surface shapes (profile and contour gagging),and surfacemicrostructures and d) dye and fluorescent penetrants and magnetic particles for enhancing the bservation of surface cracks (and sometimes near-surface conditions in the case of magnetic particle inspection).

Liquid Penetrant Testing

Flaw detection process utilizing dye penetrants are extensively used in aircraft industry. This is a logical development of the oil and chalk method popular in the early days. Briefly the method consists of immersing the part to be tested in a liquid penetrant wiping the excess panetrant and then applying a developer to bring back the dye which seeped into the flaw open to surface. The basic principle of penetrant inspection is that when a penetrant is applied over a clean surface to be inspected by the combined action of surface tension and capillary action penetrant seeps into defect which when developed, by the blotting action of the developer powder clearly shows up on a white back ground and can be conveniently inspected. The following are the basic stages on dye-penetrant method:

Surface preparation: The surface on the part to be tested is thoroughly cleaned to remove dirt.

Application of penetrant: The penetrant is a liquid of a very low viscosity, carrying a dye - generally red or a fluorescent penetrant which easily inters into flaws because of low surface tension and capillary action. The dye - penetrant may be applied on the parts by the following methods:

a. Dippingorimmersing,

b. Spraying,

c. Brushing,

d. Pouring.

Excess penetrant removal: After the parts stand in the penetrant for desired time it is washed in clean running water&dried with air.

Developer application: The developer (dry or wet) is applied by evenly spreading or dusting over the part. The developer may be chalk powder of very fine grade or wet developer which is a fine chalk powder suspended in alcohol or spirit.

Inspection: As the alcohol or spirit in the developer evaporates, the chalk powder draws back penetrant to the surface because of blotting properties of the chalk. This shows up as a redline on a white background. In case of fluorescent penetrant inspection, the part is inspected in a dark enclosure under ultra violet or black light. The blotted out fluorescent particles will give a visible glow under ultra violet light. Fluorescent penetrant inspection is very effective for machined machined and finished parts. Dye penetrant inspection is suitable for rough cast surfaces and finished surfaces.

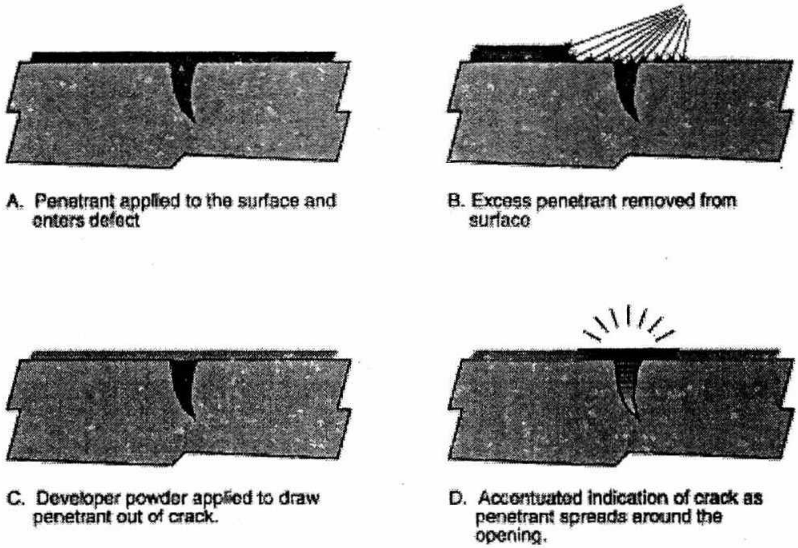


Fig. 1 : An illustration of liquid penetrant testing

Magnetic Particle Testing

Magnetic Particle Inspection is a method of locating surface and subsurface discontinuities in ferromagnetic materials. It depends on the fact that when the material or part under test is magnetized, magnetic discontinuities that lie in a direction generally transverse to the direction of the magnetic field will cause a leakage field to be formed at and above the surface of the part. The presence of this leakage field, and therefore the presence of the discontinuity, is detected by the use of finely divided ferromagnetic particles applied over the surface, with some of the particles being gathered and held by the leakage field. This magnetically held collection of particles forms an outline of the discontinuity and generally indicates its location, size, shape, and extent. Magnetic particles are applied over a surface as dry particles, or as wet particles in a liquid carrier such as water or oil. Ferromagnetic materials include most of the iron, nickel, and cobalt alloys. Many of the precipitation-hardening steels, such as 17-4 PH, 17-7PH, and 15-4 PH stainless steels, are magnetic after aging. These materials lose their ferromagnetic properties above a characteristic temperature called the Curie point. Although this temperature varies for different materials, the Curie point for most ferromagnetic materials is approximately 760 degree C.

The magnetic particle method is a sensitive means of locating small and shallow surface cracks in ferromagnetic materials. Indications may be produced at cracks that are large enough to be seen with the naked eye, but exceedingly wide cracks will no produce a particle pattern if the surface opening is too wide for the particles to bridge. Discontinuities that do not actually break through the surface are also indicated in many cases by this method, although certain limitations must be recognized and understood. If a discontinuity is fine, sharp, and close to the surface, such as a long stringer of nonmetallic inclusions, a clear indication can be produced. If the discontinuity lies deeper, the indication will be less distinct. The deeper the discontinuity lies below the surface, the larger it must be to yield a readable indication and the more difficult the discontinuity is to find by this method. Magnetic particle indications are produced directly on the surface of the part and constitute magnetic pictures of actual discontinuities. There is no electrical circuitry or electronic readout to be calibrated or kept in proper operating condition. Skilled operators can sometimes make a reasonable estimate of crack depth with suitable powders and proper technique. Occasional monitoring of field intensity in the part is needed to ensure adequate field strength. There is little or no limitation on the size or shape of the part being inspected. Ordinarily, no elaborate pre-cleaning is necessary, and cracks filled with foreign material can be detected.

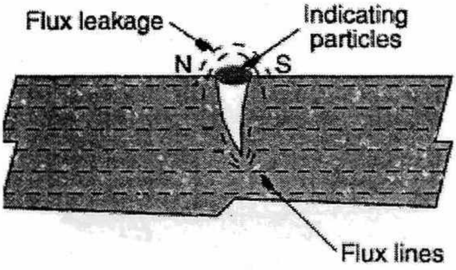


Fig. 2 : An illustration of principle of magnetic particle testing

Eddy Current Testing

Eddy current testing is based on the principle of electromagnetic induction and is used to identify or differentiate among a wide variety of physical, structural, and metallurgical condition in electrically conductive ferromagnetic and non-ferromagnetic metals and metals parts. Eddy current inspections can be used to:

- Detect surface and surface defects
- Measure or identify such condition and properties as electrical conductivity, magnetic permeability grain size heat treatment condition hardness and physical dimensions

- Sort dissimilar metal and detect differences in their composition microstructure, and other properties
- Measure the thickness of a nonconductive coating on a conductive metal or the thickness of a nonmagnetic metal coating on a magnetic metal.

Because eddy currents are created use an electromagnetic induction technique, the inspection methods does not require direct electrical contact with the part being inspected. The eddy current methods is adaptable to high –speed inspection and, because it is nondestructive can be used to inspect an inters production out put if desired .The methods is based on indirect measurement and the correlation between the instrument reading and the structural characteristics and serviceability of the part being inspected must be carefully and repeatedly established.

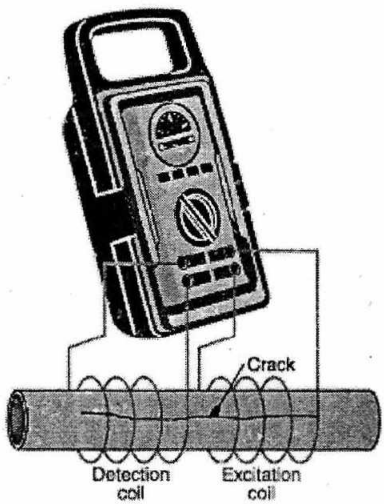


***Fig.** 3 : An illustration of an eddy current testing equipment*

The technique is extremely versatile, which has both an advantage and a disadvantage. The advantage is that the methods can be applied to many inspection problems provides the physical requirement of the material are compatible with the inspections methods. In many applications, however the sensitivity of the methods to the many properties and characteristics inherent within a martial can be a disadvantage. Some variables in a material that are not important in terms of material or part serviceability may cause instrument signals that the mask critical variables or are mistakenly interpreted to be caused by critical variables.

Radiographic Testing

Radiology is the general terms given to material inspection methods that are based on the differential absorption of penetrating radiation-either electromagnetic radiation of very short wavelength or particulate radiation-by the part or test piece (object) being inspected. Because of differences in density and variations in thickness of the part of differences in absorption characteristics caused by variation in composition, different portions of a test piece absorb different amount of penetrating radiation. These variations in the absorption of the penetrating radiation can be monitored by detecting the unabsorbed radiation that passes through the test piece.

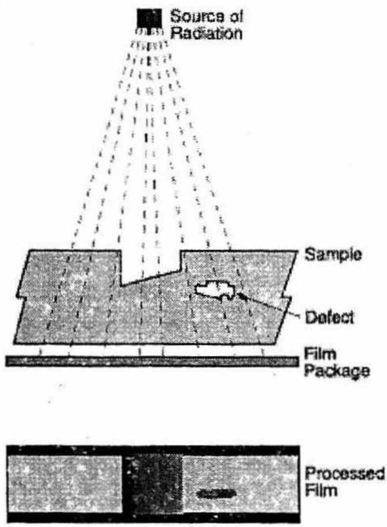


***Fig. 4** : An illustration of principle of radiographic testing*

The term radiography often refers to the specific radiological method that produces a permanent image on film (conventional radiography) or paper (paper radiography). In a broad sense, however, radiography can also refer to other radiological techniques that can produce two-dimensional, plane – view images from the unabsorbed radiation.

Film or paper radiography : A two – dimensional latent image from the projected radiation is produced on a sheet of film or paper that has been exposed to the unabsorbed radiation passing through the test-piece. This techniques require subsequent development of the exposed film or paper so that the latent image become visible for viewing

Real-time radiography (also know as radioscopy): A two – dimensional images can be immediately displayed on a viewing screen or television monitor. This technique does not involve the creation of a latent image; instead, the unabsorbed radiation is converted into an optical or electronic signal, which can be viewed immediately or can be processed in near real time with electronic and video equipment.

The principle advantage of real time radiography is the opportunity to manipulate the test piece during radiographic inspection. This capability allows the inspection of internal mechanism and enhances the detection of cracks and planar defects by manipulating the part to achieve the proper orientation for flow detection. Moreover, part manipulations in real-time radiography simplify three-dimensional (stereo) dynamic imaging and the determination of flaw location and size. In film radiography, however the position of a flaw within the volume of a test piece cannot be determined exactly with a single radiography. Consequently, other film techniques such as stereo radiography, triangulation, or simply making two or more film exposures (with the radiation beam being directed at the test piece from a different angle for each exposure) must be used to locate flaws more exactly within the test piece. Although real-time radiography enhances the detection and location of flaw by allowing the manipulation of the test piece during inspection, another important radiological technique with enhanced flaw detection and location capabilities is computed tomography. Unlike film and real-time radiography, computed tomography (CT) involves the generation of cross-sectional views instead of a planar projection. The CT image is comparable to that obtained by making a radiography of a physically sectioned thin planar slab from an object. This cross-sectional image is not obscured by overlying and underlying structures and is highly sensitive to small differences in relative density. Moreover, CT image is easier to interpret than radiographs.

Radiographic examination finds many application in inspecting casting, welding, structures etc. for internal soundness.

Ultrasonic Testing

Ultrasonic testing is a nondestructive method in which beams of high frequency sound waves are introduced into materials for the detection of surface and subsurface flaw in the material. The sound wave travels through the materials with some attendant loss of energy (attenuation) and are reflected at interface. The reflected beam is display and then analyzed to define the presence and location of flaws or discontinuities. The degree of reflection depends largely on the physical state of the materials forming the interface and to a lesser extent on the specific physical properties of the materials. For example, sound waves are almost completely reflected at metal/gas interfaces. Particular reflection occurs at metal liquid or metal/solid interfaces, with the specific percentage of reflected energy depending mainly on the ratio of certain properties of the material on opposing side of the interfaces. Cracks, laminations, shrinkage cavities, bursts, flakes, pores, disband, and other discontinuities that produce reflective inters faces can be easily detected. Inclusions and other in homogeneities can also be detected by causing partials reflection or scattering of the ultrasonic waves or by producing some other detectable effect on the ultrasonic waves. Most ultrasonic inspection instrument detect flaws by monitoring one or more of the following:

- Reflection of sound from interfaces consisting of materials boundaries or discontinuities within the metal it self
- Time of transit of a sound waves through the test piece from the entrance point at the transducer to the exit point at the transducer
- Attenuation of sound waves by absorption and scattering within the test piece
- Features in the spectral response for either a transmitted or a reflected signal

Most ultrasonic inspection is done at frequencies between 0.1 and 25 MHz – well above the range of human hearing, which is about 20 Hz to 20 kHz. Ultrasonic waves are mechanical vibrations: the amplitudes of vibrations in metal parts being ultrasonically inspected impose stresses well below the elastic limit, thus preventing permanent effect on the parts.

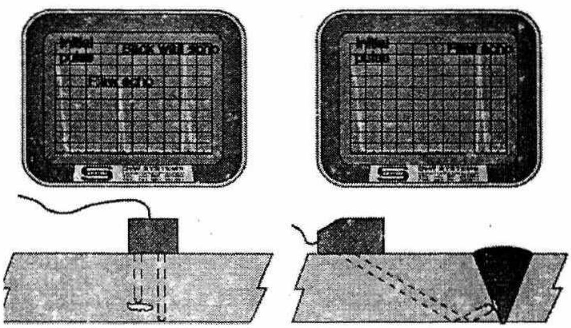
Ultrasonic inspection is one of the most widely used methods of nondestructive inspection. Its primary application in the inspection of metal of the detection and characterization of internal flaws, it is also used to detect surface flaws, to define bond characteristics, to measures the thickness and extent of corrosion, and (much less frequently) to determine physical properties, structure grain size and elastic constants.

Basic Inspection Methods

The two major methods of ultrasonic inspections are the transmissions methods and the pulse-echo methods. The primary difference between these two methods is that the transmissions methods involves only the measurement of signal attenuation, while the pulse-echo methods can be used to measure both transit time and signal attenuation.

The pulse - echo method, which is the most widely used ultrasonic methods, involves the detection of echo produced when an ultrasonic pulse is reflected from a discontinuity or an interface of a test piece. This method is used in flaw location and thickness measurement. Flaw depth is determined from the time-of-fight between the initial pulse and the echo produced by a flaw. Flaw depth might also be determined by the relative transit time between the echo produced by a flaw and echo from the back surface. Flaw sizes are estimated by comparing the signal amplitudes of reflected sound from an interface (either within the test piece or at the back surface) with the amplitude of sound reflected from reference reflector of known size or from the back surfaces of test piece having no flaws.

The transmission method, which may include either reflection or through transmission involves only the measurement of signal attenuation. This method is also used in flaw detection. In the pulse –echo methods it is necessary that an internal flaw reflects at least part of the sound energy onto a receiving transducer .However echoes from flaws are not essential to their detection. Merely the fact that the amplitude of the back reflection from a test piece is lower than that from an identical work piece known to be free of flaw implies that the test piece contains one or more flaws. The technique of detecting the presence of flaw by sound attenuation is used in transmission methods as well as in the pulse-echo methods. The main disadvantage of attenuation methods is that flaw depth cannot be measured.



a) b)

Fig.5 : *Ultrasonic flaw detection by pulse-echo method using: a) normal-beam probe and b) angle-beam probe*

Acoustic Emissions Testing

Acoustic emission is a transient elastic wave generated due to rapid release of energy from a localized source within a material due to defect formation or growth. The term "Acoustic Emission" as referred to in the field of nondestructive testing is relevant at frequency levels, which are not detectable by the human ears. We can hear the air borne sound due to the rumblings in leaves and clouds, avalanches, earthquakes etc. However, the early warning systems based on "acoustic emission" use sensors, which sense the higher frequency acoustic waves passing through solid media. When a tree trunk is partly cut by saw, and the tree starts falling by its own imbalanced weight, we do not hear the airborne sound immediately when the tree starts falling, but towards the end when the separation of the two halves of the trunk takes place. If on the other hand, we fix on the tree trunk an acoustic emission sensor of a higher frequency (say 100kHz) we would be able to detect the initial phase of the separation of the two halves of the tree trunk. Similarly, we can sense the failure of a pressure vessel when an explosion and/or a fire take place. On the other hand, AE technique if properly used can sense the impending danger much earlier. A typical AE test system includes a sensor, a pre-amplifier and a signal processor as shown schematically in figure 6.

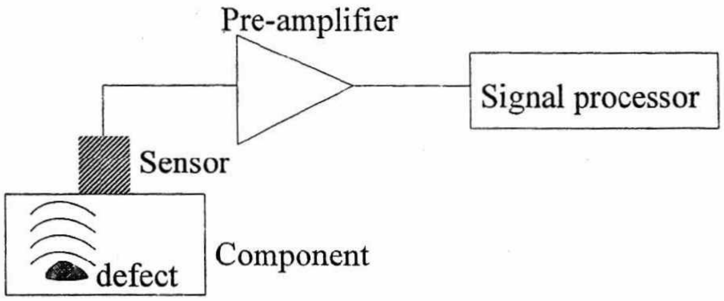


Fig. 6 *: Schematic view of an AE test system*

AE testing is a very important non-destructive test (NDT) technique which facilitates the assessment of structural integrity by detecting the presence of active (dynamic) flaws such as cracks whose growth may ultimately cause failure of the component. Sources of AE in a material include local dynamic movements, such as the initiation and propagation of cracks, active corrosion, twinning, slip or plastic deformation, sudden reorientation of grain boundaries, martensite phase transformations etc.. Of these, the AE signal intensity due to crack dynamics is generally higher than that of other sources and therefore is more likely to be detected. The others would, more probably be submerged by the background or some other innocuous noises not related to the structure at all. Of course, the AE signals due to cracks also may be submerged by the background noise or innocuous signals. This is because; the AE signals from materials having some types of microstructures are weak in energy and intensity. In such cases, depending on the situation, signal processing techniques of various complexities may be required. In the present paper, the discussion would mainly pertain to time domain signal parameters the meaning of which is explained below.

Time domain parameters of AE

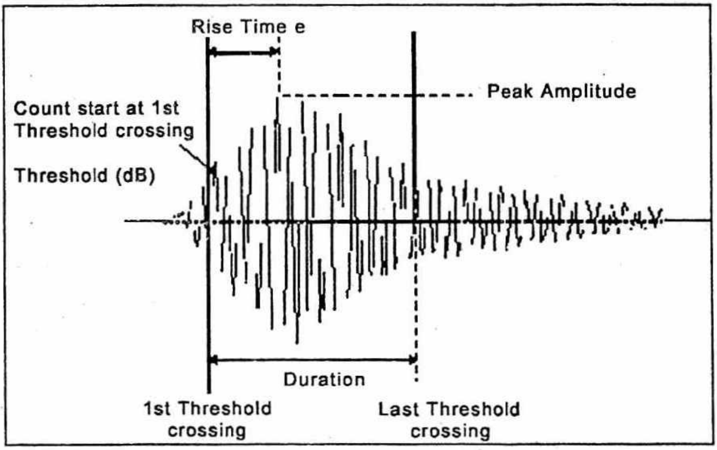


***Fig.7** : An acoustic emission waveform showing time domain parameters*

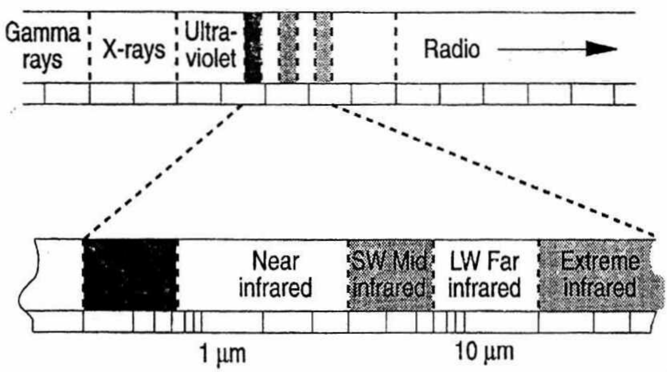
Figure 6 shows a typical acoustic emission waveform in time domain and the parameters that can be derived from it. More than one parameter is often used to get greater confidence in characterising a signal and correlating the signal with a possible source. Some of AE time domain parameters are defined below:

i) Peak amplitude: The maximum amplitude of the signal.
ii) Count (also referred to as ring down count): The number of times the signal amplitude exceeds the preset reference threshold.
iii) Count rate: The number of times the signal amplitude has exceeded the threshold in a specified period of time.
iv) Event: A microstructural phenomenon that produces micro-displacement leading to the generation of elastic waves (acoustic wave) in a material under load or stress. [In some usage the term 'hit' is used. This term is, in a way, similar to the term 'event'].
v) Rise time: The time interval between the first threshold crossing and the maximum amplitude of the signal.
vi) Duration: Time interval between the first threshold crossing and the last threshold crossing of the signal

Apart from its potential as a monitoring technique for dynamic flaws, AE analysis has attracted attention as a characterisation technique to understand various dynamic changes taking place in the microstructural and substructural conditions of a material subjected to different thermomechanical conditions For the industry however, the attraction of AE testing lies in its ability as a global monitoring technique for structures ranging from simple fluid transmission pipelines to Horton spheres to complex primary containment systems of large nuclear power plants . Its growing acceptance can be appreciated from the action that ASME has been taking for identifying the areas of application and acceptance standards.

Infrared Thermographic Testing

Our eyes only see the tiny fraction of energy emitted by the sun in the form of visible light. However, if we could see the infrared rays emitted by all bodies: organic and inorganic, we could effectively see in the dark. Though invisible to the human eye, infrared radiation can be detected as a feeling of warmth on the skin, and even objects that are colder than ambient temperature radiate infrared energy. Some animals such as rattlesnakes have small infrared temperature sensors located under each eye, which can sense the amount of heat being given off by a body. These sensors help them to locate prey and protect themselves from predators. Non-contact temperature sensors use the concept of infrared radiant energy to measure the temperature of objects from a distance. After determining the wavelength of the energy being emitted by an object, the sensor can use integrated equations that take into account the body's material and surface qualities to determine its temperature.



Infrared thermography for NDE is aimed at the discovery of subsurface features such as subsurface thermal properties, presence of subsurface anomalies/defects, due to relevant temperature differences observed on the surface with an infrared IR camera, which converts invisible infrared radiation into a visible image. IRT is deployed along two schemes, passive and active. The passive scheme tests materials and structures which are naturally at different (often higher) temperature than ambient while in the case of the active scheme, an external stimulus is necessary to induce heat.

Passive Thermography

The first law of thermodynamics concerns the principle of energy conservation and states that an important quantity of heat is released by any process consuming energy because of the law of entropy. Temperature is thus an essential parameter to measure in order to assess proper operation. Common applications of the passive scheme in NDE are for buildings, components and processes, maintenance, medicine and properties evaluation. In these applications, abnormal temperature profiles indicate a potential problem relevant to detect. In passive thermography, the key words if the temperature difference with respect to the surrounding, often referred to as the 'delta-T' or the "hot spot." A delta-T of 1 to 2 °C is generally found suspicious while a 4°C value is a strong evidence of abnormal behavior. In most of the applications, passive thermography is rather qualitative since the goal is simply to pinpoint anomalies of the type go/no-go. These applications are generally based on empirical rules applied by experienced personal.

Active Thermography

The active scheme has numerous applications in NDE. Moreover since characteristics of the required external stimulus are known somehow such as for instance the time to when it is applied, quantitative characterization becomes possible. Various techniques of active thermography are available. They include: pulsed thermography, step-heating, lockin thermography, ultrasonic lockin thermography, vibrothermography, thermo-sonic imaging, and pulsed video thermography.

6.3 CONCLUDING REMARKS

It is very difficult to weld or mold a solid object that has no risk of breaking in service, so non-destructive testing at manufacture and during use is often essential. However, there is no single NDT method around which a black box may be bult to satisfy all requirements in all circumstances.

FURTHER READING

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